national accelerator laboratory

NAL-Pub-73/22-EXP
7200.037

UCLA-1072

(Submitted to Physics Letters)

pp INTERACTIONS AT 303 GeV/c: ANALYSIS OF DIFFRACTION EXCITATION IN THE REACTION pp → pX

F. T. Dao, D. Gordon, J. Lach, E. Malamud, and J. Schivell
National Accelerator Laboratory, Batavia, Illinois 60510 USA

and

T. Meyer, R. Poster, P. E. Schlein, and W. E. Slater
University of California, Los Angeles, California 90024 USA

June 1973

Operated by Universities Research Association Inc. Under Contract with the United States Atomic Energy Commission

pp INTERACTIONS AT 303 GeV/c: ANALYSIS OF DIFFRACTION EXCITATION IN THE REACTION pp → pX

F. T. Dao, D. Gordon, J. Lach, E. Malamud, and J. Schivell
National Accelerator Laboratory, Batavia, Illinois 60510 USA

and

T. Meyer, R. Poster, P. E. Schlein, and W. E. Slater*
University of California, Los Angeles, California 90024 USA

ABSTRACT

The properties of the diffractively excited system observed at low missing mass in the inclusive pp → pX reaction at 303 GeV/c are presented. For diffraction excitation with $|x| > 0.9$, the cross section, $\sigma_D = (5.6 \pm 0.8)$ mb, the mean charged multiplicity depends on the mass of the diffractive system approximately as $\langle n_c \rangle \approx 0.6\, M_x + 2$, and the slope of the momentum transfer distribution with $|t| < 0.5$ GeV^2 is 7.5±0.8 GeV^{-2}.

An exposure of the NAL 30-in. hydrogen bubble chamber to a beam of 303 GeV/c protons has yielded 2245 events. Results have already been reported on the total cross section and multiplicity[1] and the inclusive $\Delta^{++}(1236)$ reaction.[2] In this work we report the results of a study of the slow secondary protons from the same sample of events in the reaction pp → pX.

The missing-mass spectrum from these leading protons has been studied intensively in a series of experiments by the CERN-Holland-Lancaster-Manchester group.[3] They find evidence for a low mass enhancement, which is interpreted as a diffraction excitation process. Our experiment is at a high enough energy so direct comparison with the ISR data can be made; in addition, we are able to measure the four momentum transfer, t, from the target to the final state slow proton at small values of $|t|$ and the charged particle multiplicity distribution for M_x^2, and t selections. This additional information is useful in understanding the nature of the low mass enhancement. Some data on this process was presented earlier by us.[4]

All slow positive tracks up to a projected curvature corresponding to 1.5 GeV/c were measured. Forty per cent of the final sample of protons stop in the chamber and their energy is determined by range. The rest are distinguished from pions by ionization and their energy determined from curvature. At 1.5 GeV/c the ratio of proton to pion ionization is 1.4:1.

In order to provide a clean sample of events two cuts are imposed: the maximum laboratory momentum was reduced to 1.4 GeV/c, and the fiducial volume was reduced corresponding to a track length of 45 cm (compared to 53 cm in the multiplicity analysis[1]). With these cuts 819 events containing slow protons remain, with a 100% detection efficiency for $|t| < 0.5$ GeV/c^2.

For each event the square of the missing mass, M_x^2, which recoiled from the target proton was computed. Figure 1 shows the M_x^2 distributions for 2, 4, 6, 8, 10, and > 10-prong events. The peak at small M_x^2 in the two-prong events is due primarily to elastic scattering; however, a significant asymmetric tail corresponding to inelastic two-prong events is seen at positive values of M_x^2. The most striking feature of the data is the large enhancement at low M_x^2 in the four-prong events. For the remainder of this paper we shall assume that these low-mass enhancements are diffractive and with the application of appropriate cuts they can be used to yield diffractive topological cross sections.

The two-prong M_x^2 distribution has a width of about 2.0 GeV^2; this approximates our resolution in M_x^2 (varies somewhat with M_x^2). The wider M_x^2 distribution in the four-prong events is a consequence of the physics of the diffraction excitation process. A Gaussian fit, $\exp[(M_x^2 - \overline{M_x^2})/2w^2]$, to the four-prong diffractive peak seen in Fig. 1 yields the values $\overline{M_x^2} = (7.6 \pm 0.8)$ GeV^2 and $w = (5.7 \pm 0.8)$ GeV^2 for $M_x^2 < 20$ GeV^2.

A straight-forward subtraction of elastic events from the two-prong spectrum is difficult. However, an indirect procedure can be used to obtain an upper limit on the amount of diffraction excitation in the two-prong topology. The total two-prong cross section, measured in this experiment,[1] including a correction for short unobserved or unobservable recoils, is 8.98±0.39 mb. In Ref. 1 we assumed $\sigma_{el} = 7.2 \pm 0.4$ mb. This was based on an interpolation of slope parameter data from the ISR[5] and use of the optical theorem. A more recent ISR result[6] gives $\sigma_{el} = 6.8 \pm 0.2$ at our energy. This leaves σ_{inel} (two-prong) = 2.2±0.4 mb, which can be taken as an upper limit on the diffractive component since the 2.2 mb will be a sum of both diffractive (low M_x^2) and nondiffractive contributions.

There is clearly some arbitrariness in what range of M_x^2 should be used; we may take as a guide the observation in high statistics counter experiments[3,7] that the invariant cross section has a minimum at $|x| \sim 0.9$ which is independent of s. Here we use x as the Feynman variable of the proton. We thus select events with $|x| > 0.9$, corresponding to $M_x^2 < 57\ \mathrm{GeV}^2$ at our energy and range of $P_\perp$, and find for the (single) diffraction cross sections, $\sigma_4 = (3.2\pm0.4)$ mb, $\sigma_6 = (1.1\pm0.2)$ mb, and $\sigma_{>6} = (0.5\pm0.1)$ mb. Here we have included a factor of two in the cross section because of the symmetry of the proton-proton system.

The asymmetry of the M_x^2 distribution can be used to obtain an estimate of the diffractive component in the two-prongs. If the events with $M_x^2 < m_p^2$ are subtracted from those with $m_p^2 < M_x^2 < 57\ \mathrm{GeV}^2$, one is left with 22±17 events corresponding to (0.9 ± 0.7) mb where a factor of 2 has been included (as explained above this assumes there is no overlap due to double diffraction).

Combining the 2, 4, 6, and >6-prong cross sections yields the inelastic diffraction excitation cross section of $\sigma_D = (5.6\pm0.8)$ mb. A similar enhancement for low-multiplicity events has been seen at an incident proton energy of 100 GeV[8] with approximately equal cross section (6.8±1.0 mb) lending support to the interpretation of this as a diffractive phenomena. The average number of negative tracks per collision for the diffractive enhancement can be calculated from the above numbers: $\langle n_c^- \rangle = (1.2\pm0.3)$.

The mean charge multiplicity is shown in Fig. 2 vs the Feynman variable x (for large x, $1 - x \approx M_x^2/s$ where s is the total center-of-mass energy squared). From the asymmetry of the two-prong M_x^2 distribution, one can assume there are no elastic events with $M_x^2 \gtrsim 7\ \mathrm{GeV}^2$ (or $|x| < 0.988$). Thus only the first bin in Fig. 2 is appreciably affected by the elastic-inelastic separation problem and is therefore shown as an upper and lower limit. Considering those events with $|x| > 0.9$ as examples of single diffraction excitation, we see that $<n_c>$ depends on x for this process as

$$<n_c> \approx 14\,(1 - x)^{\frac{1}{2}} + 2 \approx 0.60\, M_x + 1.$$

This approximate linearity with mass for a diffraction-type process (nova) has been predicted.[9] For $|x| < 0.9$, a much weaker dependence on x is seen.

The average charged particle multiplicity for the events in Fig. 2 is 7.02±0.33, lower than the average of 8.86±0.16 for the total sample of 2245 events.[1] This indicates that larger missing-mass events have higher multiplicity.

The distribution in momentum transfer to the diffractively-produced system (target proton to slow system) is shown in Fig. 3(a) for 4- and 6-prong events with $M_x^2 < 57$ GeV^2 ($|x| > 0.9$). The exponential shown fitted to the data has a slope, b, of 7.5±0.8 GeV^{-2}.

This diffraction slope is less than the elastic slope of ~11.6 GeV^{-2} reported at our energy,[5] but seems to be larger than the diffraction slope of ~3.5 GeV^{-2} reported in several ISR experiments.[3,10] In order to determine whether the fitted slope displays any striking dependence on M_x^2, we show in Fig. 3(b) the slope b (for 4- and 6-prongs) vs M_x^2. A very weak indication is seen for a decrease in b above $M_x^2 = 30$ GeV^2, but no firm conclusions can be drawn.

We acknowledge the support of the NAL accelerator and neutrino area operation staffs and the 30-in. chamber during the run, and the dedicated work of the staff of the NAL film-analysis facility in analyzing the data.

REFERENCES

[*] Work supported by the U. S. National Science Foundation under grant GP-33565.

[1] F. T. Dao et al., Phys. Rev. Letters 29, 1627 (1972).

[2] F. T. Dao et al., Phys. Rev. Letters 30, 34 (1973).

[3] M. G. Albrow et al., contributions to the XVI International Conference on High Energy Physics, Batavia (1972) and unpublished.

[4] E. Malamud, Recent Experimental Results at NAL, APS Meeting, Dec. 27, 1972. J. Lach et al., Bull. Am. Phys. Soc. 18, 66 (1972). See also talk by P. Slattery to be published in the Proceedings of the Vanderbilt International Conference, March 1973.

[5] B. Barbiellini et al., Phys. Letters 39B, 663 (1972).

[6] U. Amaldi et al., Phys. Letters 44B, 112 (1973).

[7] F. Sannes et al., Phys. Rev. Letters 30, 766 (1973).

[8] Rochester-Michigan Collaboration UMBC #72-14 and UR #416, January 1973.

[9] E. L. Berger et al., Phys. Rev. D6, 2580 (1972).

[10] G. Goldhaber et al., contribution to the XVI International Conference on High Energy Physics, Batavia (1972) and unpublished.

FIGURE CAPTIONS

Fig. 1. Distributions of missing mass squared (M_x^2) for 2-prong, 4-prong, 6-prong, 8-10-prong and > 10-prong events.

Fig. 2. Mean charge multiplicity vs x.

Fig. 3. (a) Momentum transfer distribution for 4- and 6-prong diffractive events with $M_x^2 < 57\ \mathrm{GeV}^2$.

(b) Slope b in $e^{-b|t|}$ vs M_x^2 for $|t| < 0.5\ \mathrm{GeV}^2$.

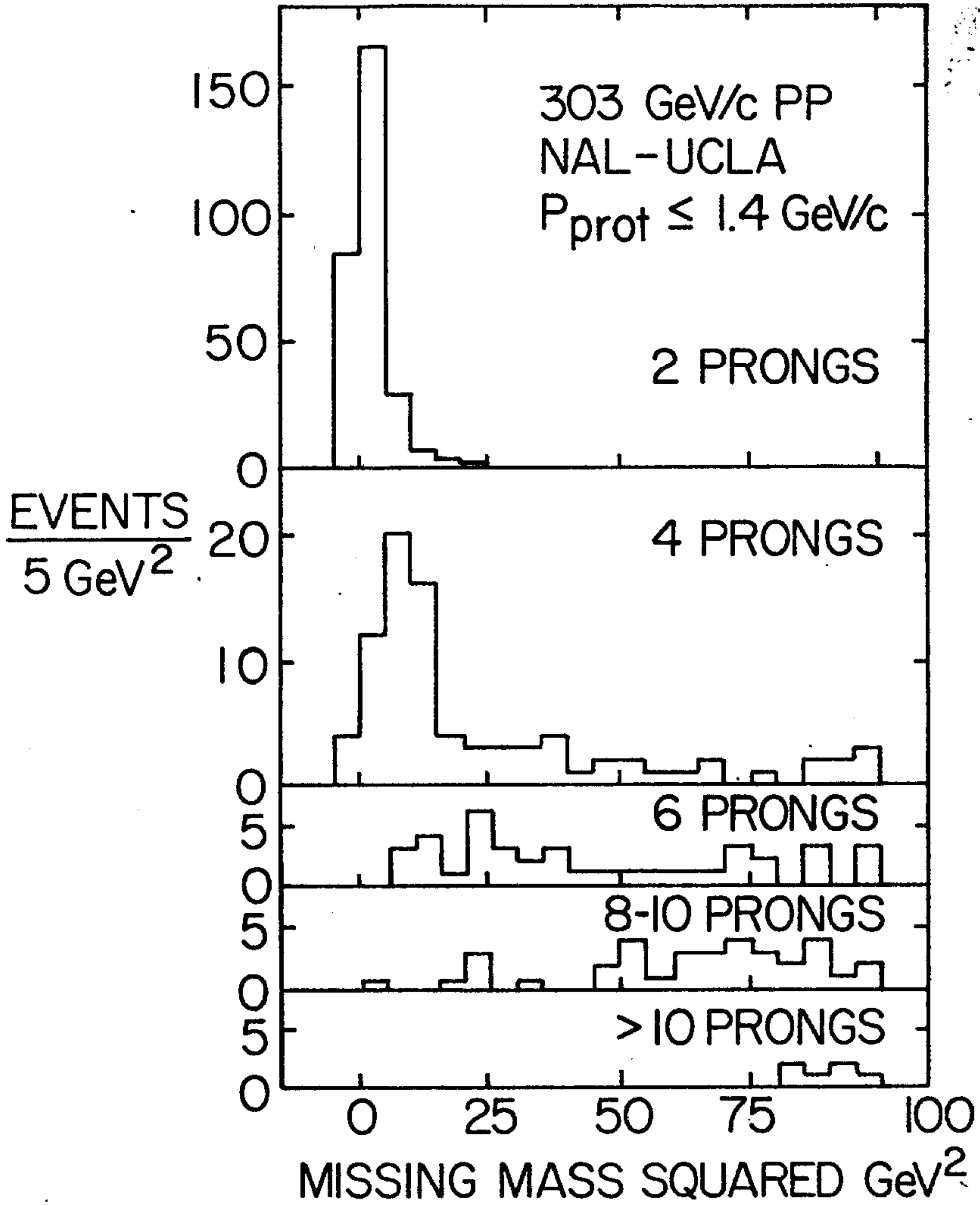
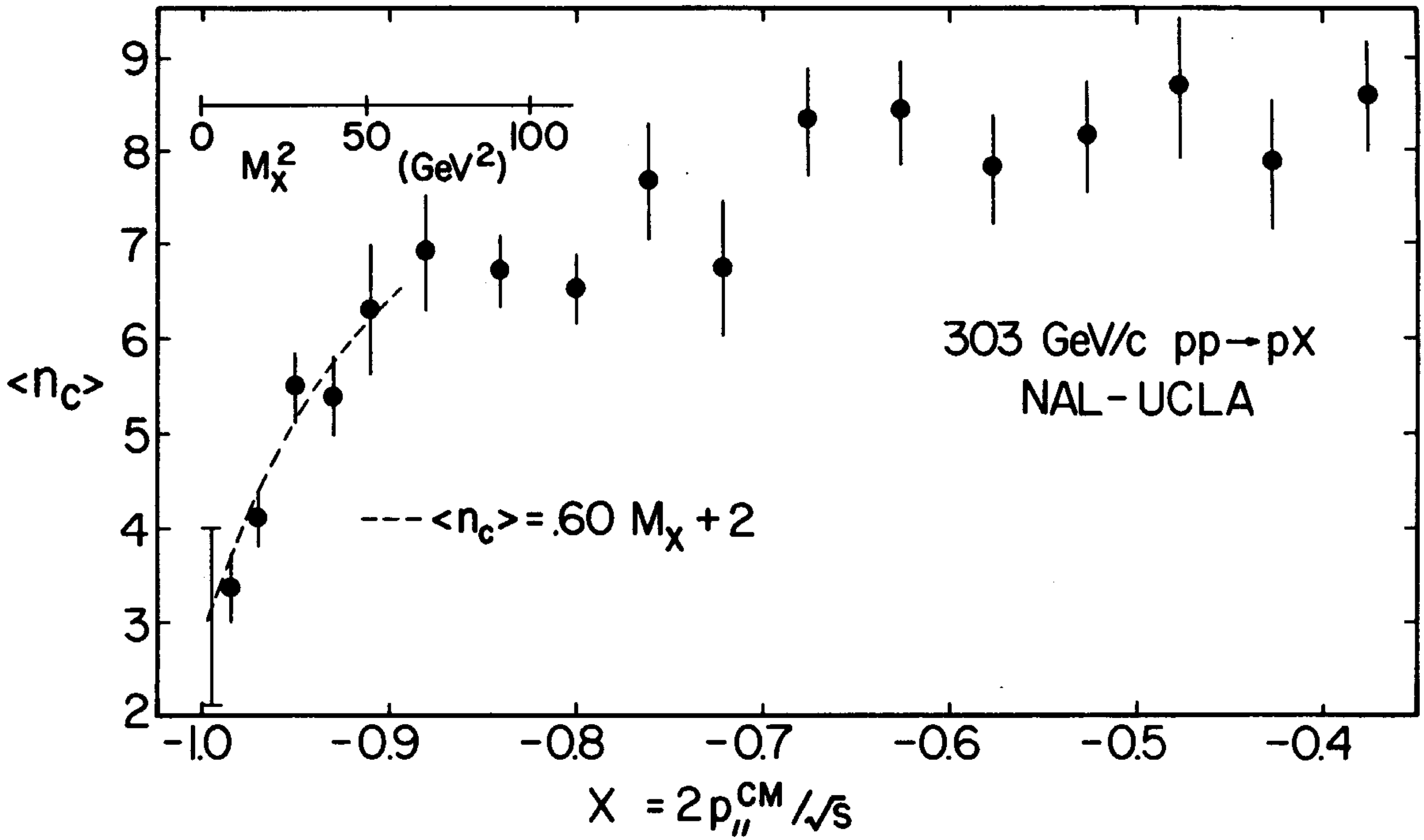
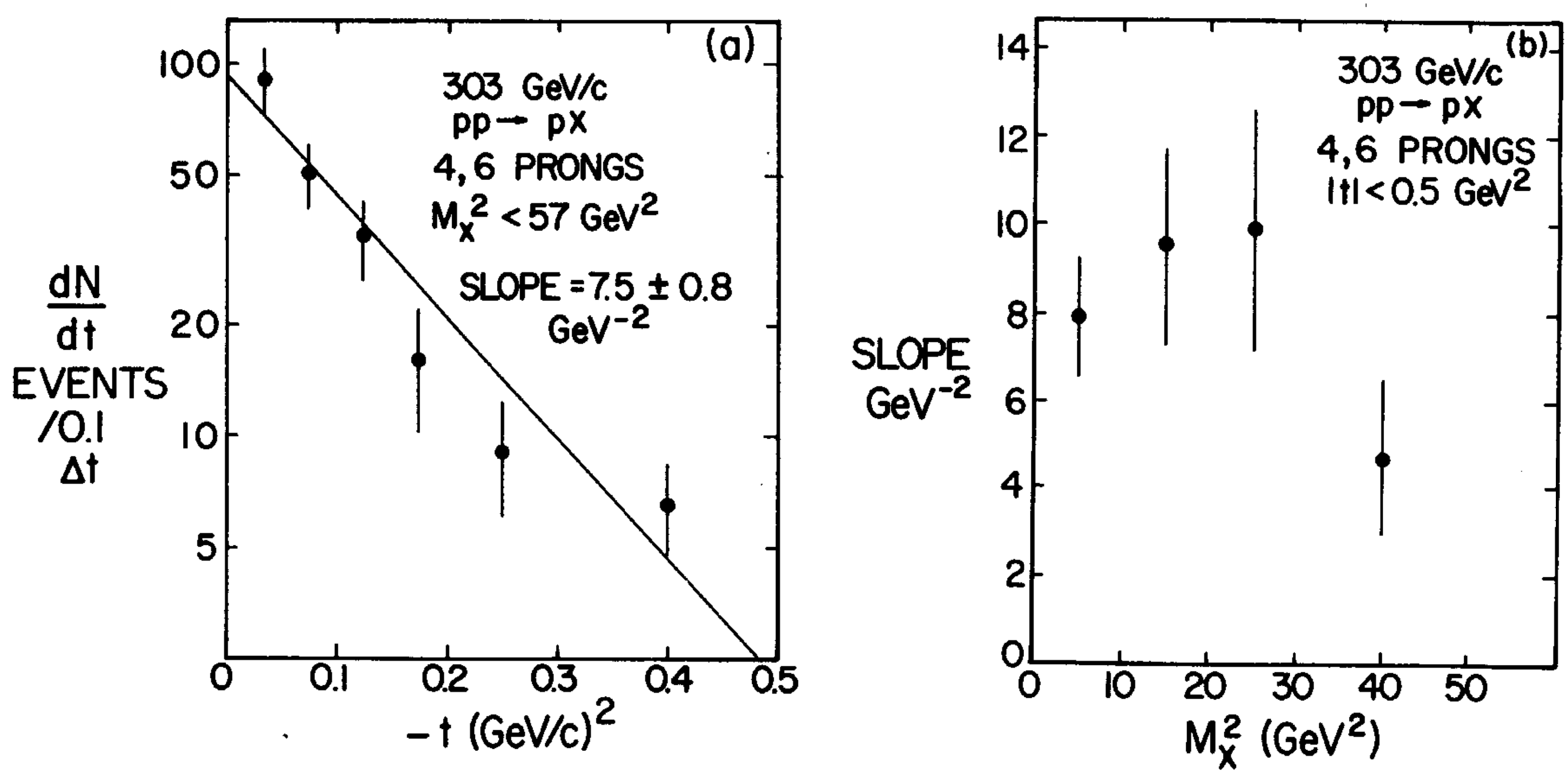

303 GeV/c PP
NAL-UCLA
$P_{prot} \leq 1.4$ GeV/c
2 PRONGS
4 PRONGS
6 PRONGS
8-10 PRONGS
>10 PRONGS
EVENTS / 5 GeV^2
150
100
50
0
20
10
0
5
0
5
0
5
0
0
25
50
75
100
MISSING MASS SQUARED GeV^2

Fig. 1



<n_c>
9
8
7
6
5
4
3
2
-1.0
-0.9
-0.8
-0.7
-0.6
-0.5
-0.4
X = 2p∥^CM/√s
0 50 100
M_X^2 (GeV^2)
303 GeV/c pp→pX
NAL-UCLA
---<n_c>=.60 M_X + 2

Fig. 2



(a)
303 GeV/c
pp → pX
4, 6 PRONGS
$M_X^2 < 57$ GeV^2
SLOPE = 7.5 ± 0.8
GeV^{-2}
$\frac{dN}{dt}$
EVENTS
/0.1
Δt
100
50
20
10
5
0
0.1
0.2
0.3
0.4
0.5
−t (GeV/c)^2
(b)
303 GeV/c
pp → pX
4, 6 PRONGS
|t| < 0.5 GeV^2
SLOPE
GeV^{-2}
14
12
10
8
6
4
2
0
10
20
30
40
50
M_X^2 (GeV^2)

Fig. 3